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Progress Report
2001 - 2003

DOE/BP-00007621-2

February 2003

This Document should be cited as follows:

Sanderson, Beth, Peter Kiffney, "Assessment of Three Alternative Methods of Nutrient Enhancement (Salmon Carcass Analogs, Nutrient Pellets, and Carcasses) on Biological Communities in Columbia River Tributaries", 2001-2003 Progress Report, Project No. 200105500, 23 electronic pages, (BPA Report DOE/BP-00007621-2)

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P.O. Box 3621
Portland, OR 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

Assessment of Three Alternative Methods of Nutrient Enhancement (Salmon Carcass Analogs, Nutrient Pellets, and Carcasses) on Biological Communities in Columbia River Tributaries

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BPA Project 2001-055-00
Contract 7621

Reporting period: May 2001-February 2003

February 2003

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Abstract

Marine-derived nitrogen, phosphorous and carbon once delivered to the rivers of the Columbia Basin by spawning salmonids are a critical part of Pacific Northwest ecosystems. Because many of the streams in which salmon spawn and rear are inherently nutrient poor, the delivery of marine-derived nutrients by returning salmon carcasses may be crucial to survival of juvenile salmon and recovery of depleted salmon populations. The recovery of Columbia Basin salmonids is contingent on the existence of fully functioning ecosystems with adequate productivity to support viable populations of salmonids. While a number of enhancement strategies for increasing the ability of streams to support salmonids exist, few studies have evaluated the methodology for enhancing stream productivity. This project takes the critical first steps of a program designed to experimentally evaluate the effects of marine derived nutrients on populations of Snake River spring/summer chinook and steelhead salmon. We are beginning a series of mesocosm and field experiments to evaluate the response if these fish and their foods to alternative methods of fertilization: (1) carcasses additions, (2) carcass analog additions (from Bio-Oregon) and (3) inorganic nutrient addition. This research is novel in that we (1) address basic questions regarding the methodology of nutrient-based techniques to enhance salmon production; (2) use a replicated before-after study design, (3) begin to distinguish between the importance of direct consumption of carcasses by juvenile salmonids from the indirect effects of bottom-up fertilization; and (4) employ a combination of economics and ecology and ask which fertilization technique provides the greatest increase in salmon performance (growth, survival, population growth) per unit dollar. Such analyses should provide a simple, intuitive method for determining which fertilization method is most cost-effective and how fertilization in general compares in cost-effectiveness to other management schemes.

Introduction

Thousands of rivers and streams dissecting the coastal lands surrounding the North Pacific Ocean once supported major populations of Pacific salmon and anadromous trout. Today, however, these once plentiful species are greatly reduced in both abundance and distribution. Fifty-six distinct North American salmonid Evolutionarily Significant Units (ESUs) have been identified, and 26 of these are now listed as threatened or endangered under the U.S. Endangered Species Act. The grim outlook for Pacific salmonids was re-emphasized by the National Marine Fisheries Service (NMFS) with analyses showing 10 of the 11 ESUs they investigated in the Columbia River Basin continuing their decline with 4 of these decreasing at rate of 10% per year (McClure et al., 2003).

Recent research has highlighted that the importance of returning salmon goes far beyond the clear need for reproducing adults (Stockner, 2003, Schindler et al. 2003, Gende et al. 2002, Naiman et al. 2002, Bilby et al. 2001). Because more than 95% of the body mass of salmon is accumulated while fish are in the sea, the return of adults represents a transfer of nutrients from marine to freshwater and terrestrial habitats. The nutrients derived from decomposing salmon carcasses (marine-derived nutrients) are now recognized to play an important role in the ecology of the Pacific Northwest (Gresh et al. 2000, Naiman et al. 2002). Indeed, the importance of this subsidy has been suspected for some time. Sockeye salmon were estimated to transport 2 million kg of organic material and 5000kg of phosphorus to the Karluk River System in Alaska (Juday et al. 1932). Similarly, sockeye salmon carcasses were suggested to provide up to 40% of the annual phosphorus budget to lakes and rivers throughout Alaska (Donaldson 1967; Mathisen 1972; Mathisen et al.1988; Kline et al. 1994) and Russia (Krokhin 1975).

Many of the systems in which salmon spawn and rear are inherently nutrient poor. Consequently, the delivery of marine-derived nutrients by returning salmon carcasses appears to be crucial to the growth and survival of juvenile salmon (Larkin and Slaney 1997, Bilby et al. 1996, 1998, Wipfli et al. 1998). Juvenile salmon consume both salmon eggs and the bodies of adults after they have spawned. Young salmon are also likely indirect beneficiaries of increased primary production and insect abundance associated with salmon carcasses (Kline 1990,Wipfli et al. 1998). As a result, the drastic decline in salmon abundance throughout the Pacific Northwest, in general, and the Columbia River Basin, in particular, must be viewed as not only an economic and aesthetic loss, but also an ecological loss (Gresh et al. 2000, Naiman et al. 2002). The lack of spawning adults has likely lead to a substantial nutrient deficit that has contributed to the downward spiral of salmon abundance in the Columbia Basin (Gresh et. al. 2000). The recovery of Columbia Basin salmonids is contingent on the existence of fully functioning ecosystems with adequate productivity to support viable populations of salmonids. While a number of enhancement strategies for increasing the ability of streams to support salmonids exist, few studies have rigorously evaluated the methodology for enhancing stream productivity. Our research is

designed to experimentally evaluate the effects of marine derived nutrients on populations of Snake River spring/summer chinook and steelhead salmon.

Background on Nutrient Enhancement Strategies

For the past two summers, we have monitored baseline conditions of stream habitat, nutrient chemistry, and algal biomass and insect biomass, abundance and diversity. This summer we have planned a series of controlled mesocosm and field experiments to evaluate the response of salmonids (spring/summer chinook salmon and steelhead) to alternative methods of fertilization. We are evaluating three methods of enhancement: 1) carcass additions, 2) carcass analog additions and 3) inorganic nutrient addition. These forms of enhancement involve addition of organic or inorganic nutrients and may differentially affect juvenile salmonid growth and survival.

The first approach, nutrient enhancement via carcasses is becoming an increasingly popular management strategy. In August 2000, Washington Department of Fish and Wildlife announced it would be distributing hatchery carcasses for stream nutrient enhancement in at least a dozen streams (WDFW Fact sheet, http://www.wa.gov/wdfw/factshts/howsurplus.htm). Similar programs are in operation in the state of Oregon (http://www.dfw.state.or.us/ODFWhtml/InfoCntrFish/whathappens.pdf). Although carcass enhancement is being adopted as a management strategy, more and more, major issues remain. First, there is a paucity of scientific information to guide managers in basic methods and protocols. Fundamental questions such as how many carcasses are needed, where and at what time should carcasses be deposited, and in which streams might carcass enhancement be most effective remain unaddressed. Second, the increasing use of carcass enhancement in streams has not been coupled with appropriate monitoring and evaluation programs. Subsequently, the opportunity to broadly evaluate the extent to which salmonids benefit from such actions has been lost. If appropriately designed and monitored, data from enhancement programs can be used to quantify how much improvement in salmonid population growth rate we might expect. This information is vital to all those in the region trying to design effective and efficient recovery strategies. Third, as a result of a concern for spreading pathogens, most salmonid enhancement programs permit the addition of only those carcasses that originate from the same watershed. Finally, whereas carcass additions are feasible in systems relatively accessible by roads, the feasibility of broadly applying carcasses enhancement techniques in less accessible areas is much lower given time and resource demands.

A second approach to enhancing productivity of salmonids via fertilization involves increasing the system's productivity via bottom-up processes using the addition of inorganic nutrients. The addition of inorganic nutrients increases primary producer biomass, subsequently increasing the biomass of higher order producers (invertebrates, fish, riparian vegetation and other wildlife). The BC Ministry of Environment has been conducting a long-term fertilization experiment

on the Keogh River in British Columbia using slow release nutrient briquettes that release inorganic nutrients. During this period, they have observed increases in growth and survival rates and numbers of salmonid and non-target fish species (McCubbing and Ward 1997). Recent results indicate that increases in growth rate were concomitant with a shift in life-history strategy in which outmigration of juvenile steelhead occurred one year earlier. As with the carcass enhancement technique, experiments in stream fertilization must address a number of issues. The first issue involves identifying the appropriate levels at which to fertilize and the timeframe over which a response may occur. Short-term, local responses to fertilization are well documented (Johnson et al. 1990, Wipfli et al. 1999, Kiffney and Richardson 2001), but the time needed to build overall system productivity is much longer. Furthermore, a long-term commitment to fertilization may be needed to instigate a positive feedback cycle in which added nutrients stimulate production, salmon growth and survival, and ultimately result in increasing numbers of adult returns bringing more nutrients to the system.

A third approach involves using salmon carcass analogs, a new product being developed by Bio-Oregon. Bio-Oregon has developed assorted fish feed used in the aquaculture industry (http://www.bio-oregon.com/flash/index.htm), and is working to develop a carcass analog that will not immediately dissolve when placed in-stream. The carcass analogs will be derived from fishmeal and processed using a pasteurization technique intended to minimize the likelihood of pathogen transfer to streams. Given their compact size, carcass analogs are more easily distributed than actual carcasses. Uncertainties associated with nutrient enhancement via carcass analogs are whether and to what extent these analogs will be directly consumed by fish and other vertebrates or whether these analogs will function more like inorganic fertilizer briquettes. Furthermore, we are unsure how long analogs will remain in-stream compared to true carcasses. Already, there is considerable interest within the region in this yet undeveloped technology (Dennis Roley, Bio-Oregon, personal communication). It is therefore imperative that these analogs be first used in tightly controlled and monitored experiments.

Our research program involves a comparative, experimental approach that has the following elements. First, we address basic scientific questions regarding the methodology of enhancement techniques in an effort to identify the best strategy to fertilize streams in order to increase salmon production. We will compare a novel enhancement technique still under development (carcass analogs) to two enhancement strategies that need to be quantitatively evaluated in an experimental setting (carcasses and inorganic fertilizers). Second, we can begin to distinguish between the relative importance of direct consumption of carcasses by juvenile salmonids and the indirect effects of bottom-up fertilization. Third, these experiments are the first step in evaluating short and long-term effects of differing methods of enrichment. The results from this research will be of great use to management, as this approach evaluates enrichments methods that differ in cost and effort needed to implement. Furthermore, we are testing these approaches at multiple scales, which allow us to identify mechanisms as well as generate results that have direct relevance to management. The ability to link anticipated benefits

for salmonids to specific management actions is a vital need throughout the Columbia River Basin. This need to know 'how much bang for the buck' will only amplify as recovery plans are developed and actions prioritized.

Research Sites and Timeline

Our study streams are located in three drainages of the Salmon River Basin, Idaho (Table 1, Figure 1). Rocks of the Atlanta lobe of the 70-80 million year old Idaho batholith dominate the geology of this region. This large form occupies the most of the land area of central Idaho, and is responsible for the dominant character and form of the regional landscape. Glaciers covered much of the region as recently as 10,000 years ago; glacial processes have contributed immensely to the form and function of the streams in this basin. Our research sites include 18 streams located within National Forests (Payette, Salmon, Challis and Boise National Forests) and/or Wilderness and Recreation areas (Sawtooth National Recreation Area). Our study reaches range from moderately confined to unconfined in moderately wooded and meadow landscapes.

Our research plan combines baseline monitoring of treatment and control reaches within each study stream, enclosure experiments in 1-2 streams, stream channel experiments, and a large-scale ecosystem experiment in which carcasses, inorganic nutrients and analogs are added to streams (Table 2). These research streams coincide with those studied as part of the ongoing wild-fish monitoring study (Steve Achord, BPA project #19102800) which has measured the survival and size of PIT tagged wild chinook for the last decade from streams we will use as treatments and controls. In addition, this long-term database allows us to employ statistical techniques for determining the efficacy of each of our experimental treatments. We will thus be able to estimate changes in juvenile survival, size and condition as a function of experimental treatment.

Permits

The following is information on permits requested and received for work in 2002 and 2003. Additional permits will be required in 2004 to cover the nutrient enhancement experiment.

Permits 2002

USFS National Forest Permits

- Boise (ID#BOI003601, issued8/1/02, no invertebrate sampling permitted)
- Payette (ID#MCC033, issued 8/09/02)
- Salmon-Challis (Yankee Fork sites approved; Middle Fork sites were not)
- Sawtooth National Recreation Area (File Code 2700, issued 8/22/02)

ESA Permit (#1056, Study 3)
IDFG Permit Request (Not Approved)

Permits 2003

USFS National Forest Permits

- Boise (submitted)
- Payette (submitted)
- Salmon-Challis (submitted)
- Sawtooth National Recreation Area (submitted)
- Boise National Forest Biological Assessment of Invertebrate Sampling and Stream Enclosure Experiments (Level 1 meeting scheduled to review BA on 4/30/03)

ESA Permit Section 10 (Salmon and Steelhead: #1402, submitted 1/9/03, in review)
ESA Permit Section 7 (Bull Trout; permit # 1-7-00-F-336, Study 2 request under review)

2002 Baseline Monitoring: Progress and Methods

Field sampling began in August 2002 following contract approval (June 2002) and the issuance of USFS permits from the Boise, Payette, and Salmon-Challis National Forests and the Sawtooth National Recreation Area (July and August 2002). Variables monitored included nutrient chemistry, primary production, invertebrate community, and physical habitat (Table 3). Specific response variables are presented in Table 4. Each stream was sampled 1-2 times during August and September 2002. Loon and Camas Creeks were not sampled due to time constraints and unresolved permit issues.

Physical Habitat Characterization: Physical habitat was measured using standard methods from the EPA Environmental Monitoring and Assessment Protocol (Kaufmann and Robison 1998). This method consists of measuring a suite of physical channel parameters that describe the character of a given reach. A 40-channel width-reach was surveyed in each stream. We characterized stream width, gradient, channel and habitat characteristics (habitat type, sinuosity, substrate composition, water depth), and riparian vegetation. We also conducted two Wolman pebble counts at 3-5 riffles in the mapped reach.

Water Chemistry: Water samples were collected to measure nutrient concentrations (PO_4, $Si(OH)_4$, NO_3, NO_2, NH_3), and total nitrogen (TN) and total phosphorus (TP) concentrations. These samples were collected from riffle habitats at 5 randomly chosen transects at each stream. Nutrient samples were filtered through a 0.45 um cellulose acetate membrane filter. Samples were stored in polypropylene sample bottles and kept frozen until analysis. All water chemistry samples were analyzed by the WA accredited Marine Chemistry Lab at the School of Oceanography (Univ. of WA).

Primary Production: To measure algal biomass, we removed periphyton from two rocks from each of five riffles in each stream. Scraped periphyton was diluted into a slurry and filtered onto glass fiber filters. Filters were processed for chlorophyll and ash free dry mass (AFDM) (Steinman and Lamberti 1996). Filters to be used for AFDM were ashed at 500°C for 4 hours and weighed. Following filtration, filters were dried thoroughly at 70°C, weighed and subsequently ashed at 500°C for 4 hours, and weighed again. Chlorophyll filters were frozen until analysis. Chlorophyll concentrations were measured fluorometrically (Turner Designs Fluorometer, TD-700). Filters were extracted in 90% acetone for 24 hours prior to measurement.

Invertebrate Community Composition: Invertebrates were sampled using a 362um mesh Hess sampler (Hauer and Resh 1996). Sediment was disturbed for one minute. Samples were elutriated and sieved to remove non-invertebrate materials, and preserved in 95% ethanol. Taxa were enumerated and identified to the lowest taxonomic level (genus when possible).

Isotope Analysis: Periphyton samples for isotope analyses were collected from streams accessed a second time and kept frozen until they were freeze-dried, ground and weighed. Fractionation of the stable isotopes nitrogen-15 ($_{\delta}N_{15}$) and carbon-13 ($_{\delta}C_{13}$) was analyzed using a Costech elemental combustion system (model 4010) coupled to a Thermo Finnigan Delta Plus mass spectrometer.

2002 Field Season Results

Baseline data collected in 2002 and 2003 will be used to identify appropriate treatment and control streams for the nutrient enhancement experiment in 2004. Furthermore, these data are providing pre-treatment data that will be needed to statistically evaluate responses to the manipulation.

Water Chemistry and Periphyton: Ranges of water chemistry and periphyton biomass data are presented in Table 5. Nitrate and phosphate concentrations were often near zero or extremely low (Figure 2). Chlorophyll concentration and ash-free dry mass measurements were correlated (r = 0.67), despite the differences in their distributions and variation (Figure 3, Table 5).

Ph*ysical Habitat:* Average wetted widths ranged from 3-27 meters (Table 6). Stream gradients were less than 1% in ten of the fourteen streams for which habitat characteristics were completed. Pebble size was consistently small in several streams (Elk, Sulphur, Summit); pebble sizes were much largest in the Secesh River and Chamberlain Creek (Figure 4).

Invertebrates: Approximately thirty different aquatic invertebrate taxa were collected from Secesh River and Summit Creek (Table 7). Remaining invertebrate samples are being processed.

2003 Research Plan

Our summer 2003 research program includes three elements: baseline monitoring, stream enclosure experiments, and stream channel experiments. We have added the stream enclosure experiments to our original proposed design for three reasons. First, because of contract litigation we were unable to collect a full year of baseline data in 2002 and subsequently, the nutrient enhancement experiment is delayed until 2004. Given the pressing needs for identifying potentially useful recovery strategies and the growing interest in nutrient subsidies, it is important to start examining the relative benefits to fish of these differing nutrient enhancement techniques. Second, by beginning this research at a smaller-scale, we hope to begin addressing some of the regional concerns about nutrient enhancement in general. Third, this comparative experiment within a single stream is a powerful tool for isolating cause-effect relationships in freshwater ecosystems. In contrast, experimental manipulation across multiple natural streams is sometimes confounded by the great variability among streams. We will use the results of all three elements (baseline data, mesocosm and enclosure experiments) to guide our decisions about how to fertilize in natural systems.

The specific aspects of this summer's research plan are described in Tables 2 and 4. In the summer of 2003, we will add the following variables to our baseline-monitoring program: nutrient limitation experiments, periphyton colonization dynamics, invertebrate drift, fish abundance, community composition and growth rate, leaf litter decomposition, and isotope composition of fish and invertebrates.

Table 1. Names and locations of research streams monitored during summer 2002.

Drainage	Forest	Stream	Latitude	Longitude
Salmon River	Payette	Chamberlain Creek	45.21.694	115.13.534
	Payette	West Fork Chamberlain	45.24.859	115.11.673
	Boise	South Fork Salmon River	44.34.900	115.40.958
South Fork Salmon River	Payette	Lake Creek	45.20.342	115.56.945
	Payette	Secesh River	45.11.737	115.49.206
	Payette	Summit Creek	45.14.527	115.54.621
Middle Fork Salmon River	Boise	Bear Valley Creek	44.23.487	115.22.492
	Payette	Big Creek (Upper)	45.06.050	115.19.837
	Salmon-Challis	Camas Creek	44.48.762	114.29.198
	Challis	Loon Creek	44.36.708	114.47.717
	Boise	Elk Creek	44.25.317	115.25.612
	Sawtooth	Elk Creek Trib to Valley	44.17.551	115.01.497
	Payette	Big Creek (Lower)	45.06.628	114.54.054
	Challis	Cape Horn Creek	44.21.559	115.12.263
	Challis	Marsh Creek	44.22.239	115.08.389
	Payette	Rush Creek	45.05.871	114.51.838
	Salmon-Challis	Sulphur Creek	44.32.578	115.20.086
	Sawtooth	Valley Creek	44.14.050	114.59.376

Table 2. Timing and nature of research activities for the Salmon River nutrient enhancement study.

	2002	2003	2004 & beyond…
Baseline Monitoring	X	X	X
Stream enclosure experiments		X	X
Stream channel experiments		X	X
Ecosystem nutrient enrichment experiment			X

Table 3. Type and frequency of data collected from Salmon River study streams (2002).

WHERE		DATA COLLECTION FREQUENCY (# times visited from August - September 2003)			
Stream	Forest	Water Chemistry	Primary Productivity	Invertebrate Community	Physical Characterization
		water collection	rock scraping	Hess sampling	habitat survey
Secesh River	Payette	2	2	1	completed
Lake Creek	Payette	2	2	1	completed
Summit Creek	Payette	2	2	1	completed
West Fork Chamberlain Creek	Payette	1	1	1	completed
Chamberlain Creek	Payette	1	1	1	completed
Upper Big Creek*	Payette	1	1	0	completed
Lower Big Creek	Payette	1	1	1	completed
Rush Creek	Payette	1	1	1	completed
South Fork Salmon River	Boise***	2	2	0	completed
Elk Creek	Boise***	1	1	0	completed
Bear Valley Creek	Boise***	2	2	0	completed
Loon Creek**	Challis				
Camas Creek**	Salmon-Challis				
Sulphur Creek	Salmon-Challis	1	1	1	completed
Cape Horn Creek	Challis	2	2	2	completed
Marsh Creek ^	Challis	2	2	2	not completed
Valley Creek	Sawtooth	2	2	2	completed
Elk Creek Trib to Valley	Sawtooth	2	2	2	completed

* Permitted reach was too high gradient for complete sampling

** Sites not accessed due to permitting and scheduling conflicts

*** Invertebrate collection not permitted in the Boise National Forest

^ Habitat survey not completed due to high spawner densities

Table 4. Variables monitored during baseline data collection in the summer of 2002 and additional variables that will be monitored during summer 2003.

Data Category	Variables Measured in 2002	Additional Variables for 2003
Physical Characterization	Channel Width -bank full width -wetted width Gradient Channel characteristics -habitat type -sinuosity -substrate composition -water depth Riparian Vegetation Pebble counts	Temperature -maximum daily -minimum daily -mean daily Flow Rate
Water Chemistry	Total - Nitrogen - Phosphorus Nutrients - PO_4, $Si(OH)_4$, NO_3, NO_2, NH_3	Dissolved Organic Carbon Turbidity
Primary Productivity	Periphyton Biomass (rocks) - ash free dry mass - chlorophyll concentration Isotope Composition	Periphyton Biomass (tiles) - ash free dry mass - chlorophyll conc.
Invertebrate Community	Community biomass and density Species composition	Isotope composition
Decomposition		Leaf litter decomposition rate
Fish Community	Individual survival (Achord Study)	Species composition Abundance/Density/Biomass Size structure Individual length and weight - growth rate - condition Isotope Composition

Table 5. Summary of water chemistry and periphyton data from 15 streams sampled in summer 2002. Included are the minimum, maximum, mean and standard deviation of values observed across all streams. Nutrients, total phosphorus (TP) and total nitrogen are in concentration units (µg/L). Ash-free dry mass (AFDM) and chlorophyll are calculated on an aerial basis (mg/cm^2, and ug/cm^2).

	Mean	Minimum	Maximum	Standard Dev
PO_4	3.61	0.29	16.24	3.37
SiO_4	5955.45	3967.33	8993.05	1289.60
NO_3	3.22	0.00	24.29	6.54
NO_2	0.13	0.00	0.34	0.09
NH_4	3.34	1.19	6.25	1.17
TP	28.93	17.44	49.37	7.40
TN	166.69	99.35	280.82	37.25
AFDM	0.30	0.08	0.56	0.13
CHL	25.71	1.12	151.34	32.85

Table 6. Average wetted width, and the minimum, maximum and average gradients (%) in sampling reaches. (N) indicates number of transects measured within sampling reach.

		Stream Gradient (%)			
	Average Wetted Width (m)	Average	Minimum	Maximum	N
Bear Valley	10.9	0.31	0.05	0.56	8
Cape Horn	5.8	0.74	0.00	1.14	10
Chamberlain	9.3	1.92	0.83	3.46	10
Elk Creek	13.1	0.10	0.00	0.52	10
Elk Creek Trib	6.3	1.22	0.40	3.10	10
Lake Creek	4.3	0.84	0.06	1.27	7
Lower Big	27.2	0.89	0.00	1.27	10
Rush	8.7	1.56	0.68	2.73	10
Secesh	17.5	0.91	0.42	1.75	10
SF Salmon	9.8	0.74	0.09	1.32	10
Sulphur	11.1	0.31	0.00	1.16	10
Summit	7.0	0.47	0.09	1.50	10
Valley	14.6	0.36	0.14	0.75	10
WF Chamberlain	3.4	1.76	0.34	3.31	10

Table 7. Number of aquatic invertebrate taxa collected from 5 benthic samples (Hess samples) in Summer 2002.

	Secesh River	**Summit Creek**
Ephemeroptera (Mayflies)	7	11
Trichoptera (Caddisflies)	10	6
Plecoptera (Stoneflies)	4	4
Diptera (True Flies)	3	4
Other Taxa[1]	6	7

[1] Other taxa include water beetles, mites, oligochaetes, leeches, back-swimmers, ostracods, hydra, freshwater clams and semi-aquatic spring-tails.

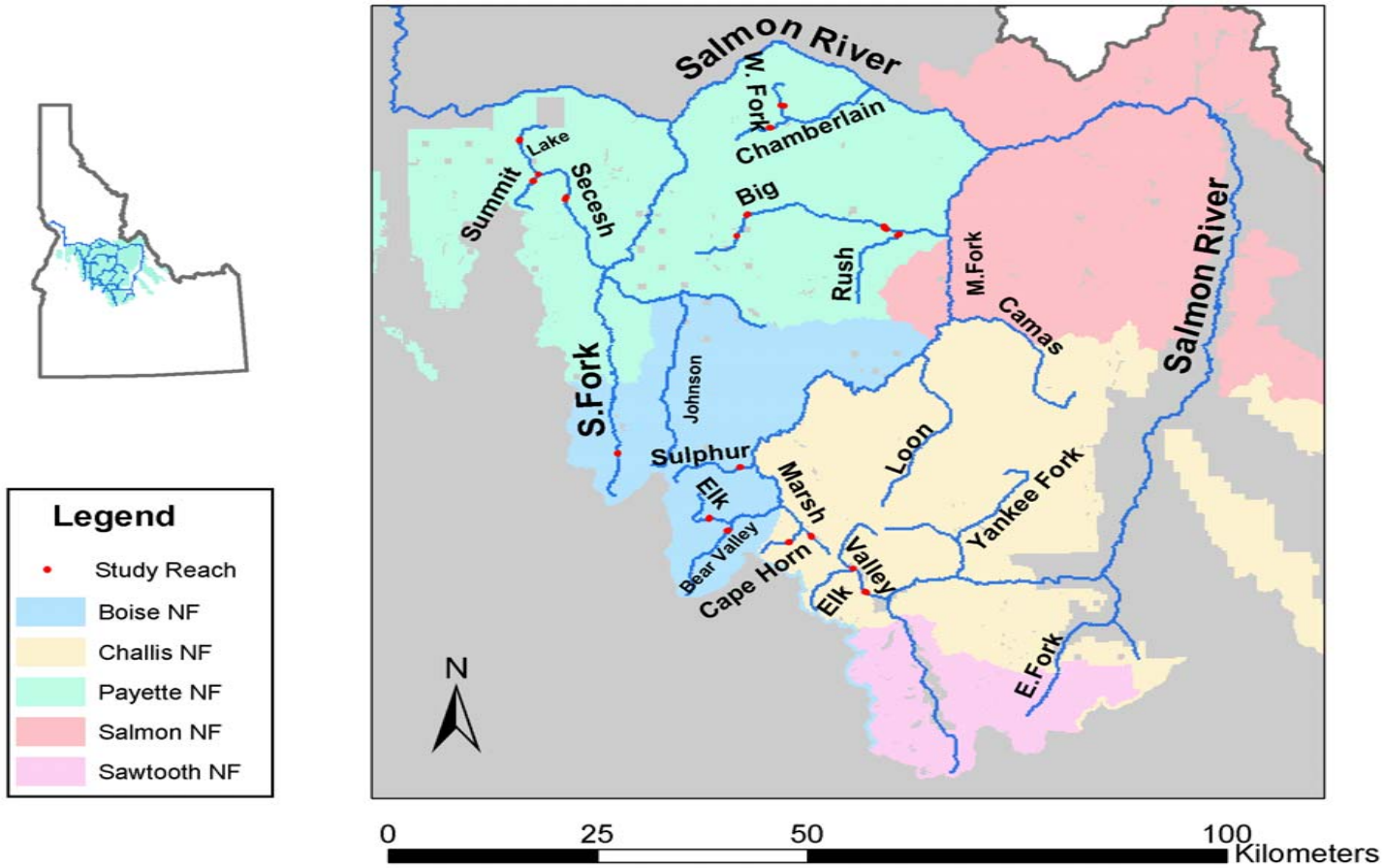

Figure 1. Map of study streams in the Salmon River Basin. Dots on individual streams identify the location of sampling reaches. Shading depicts the five different National Forests.

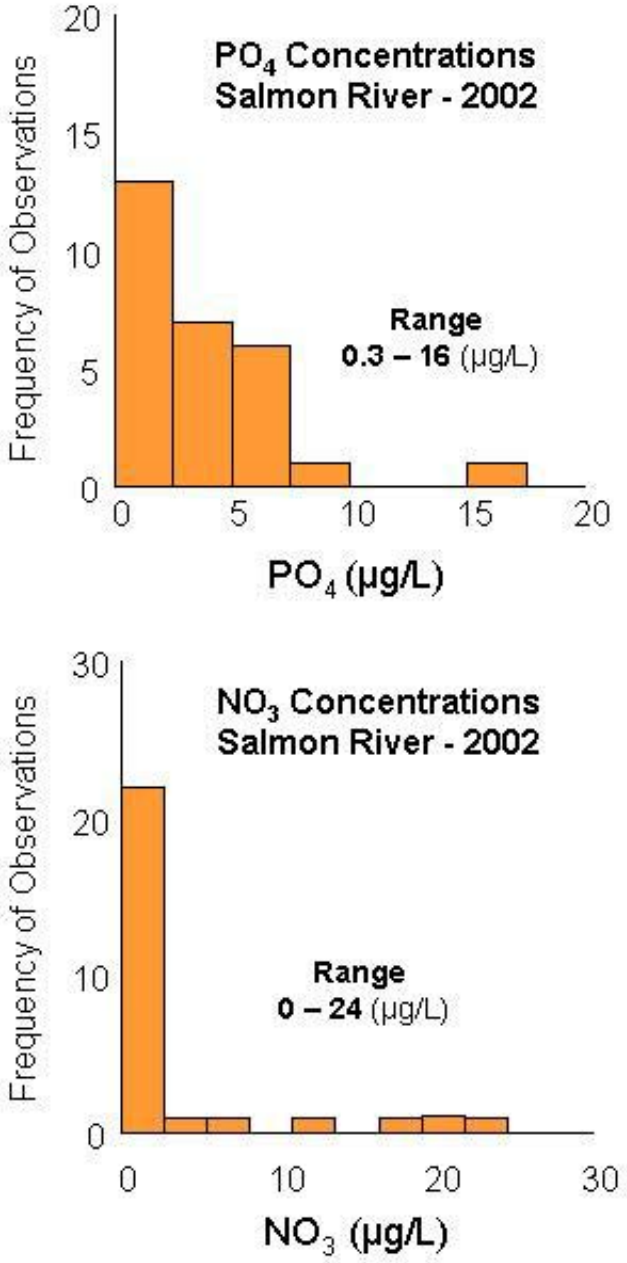

Figure 2. Histograms of phosphate (PO_4) and nitrate (NO_3) concentrations measured in the 16 streams sampled in 2002. Observations include two sampling points for a subset of the streams sampled a second time.

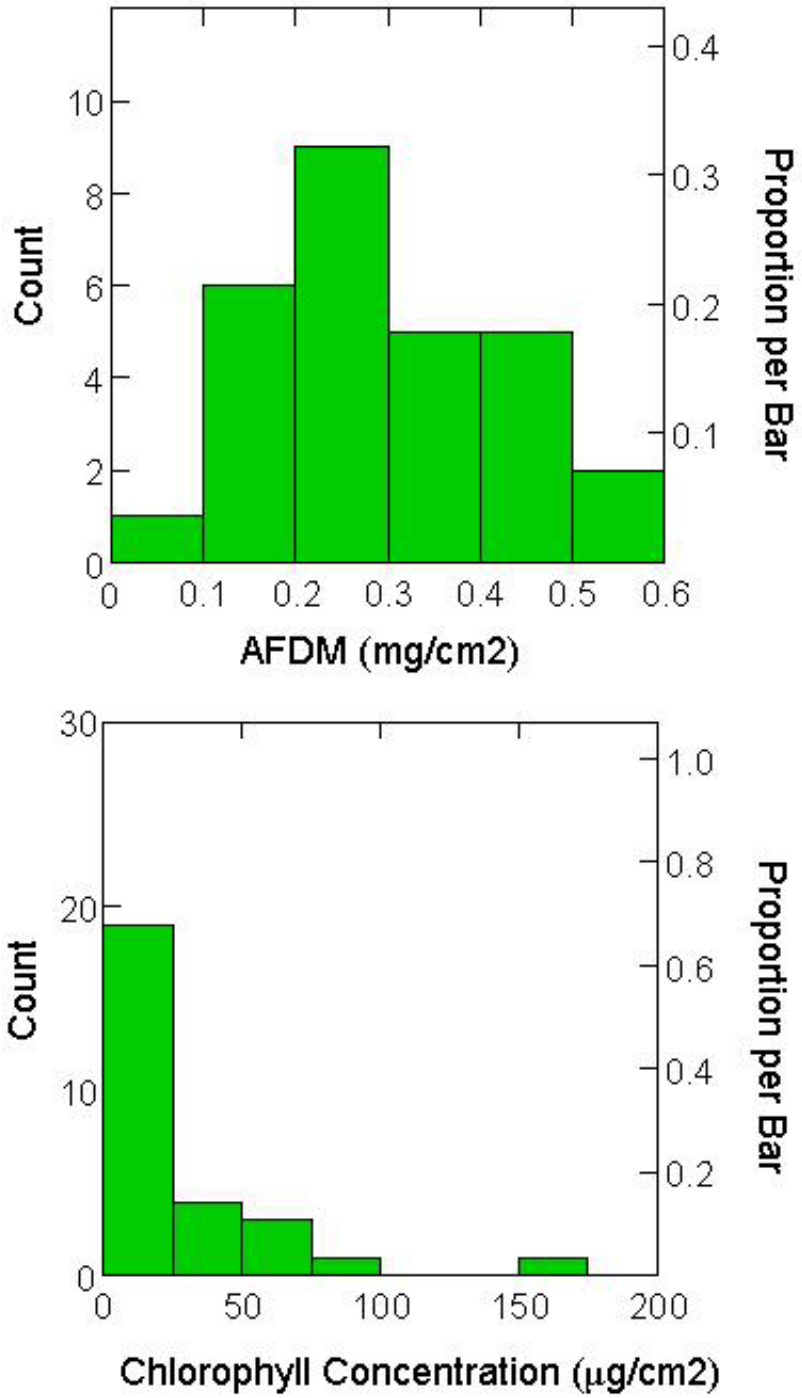

Figure 3. Histogram of ash-free dry mass (AFDM) and chlorophyll concentrations measured in the 16 streams sampled in 2002. Observations include two sampling points for a subset of the streams sampled a second time.

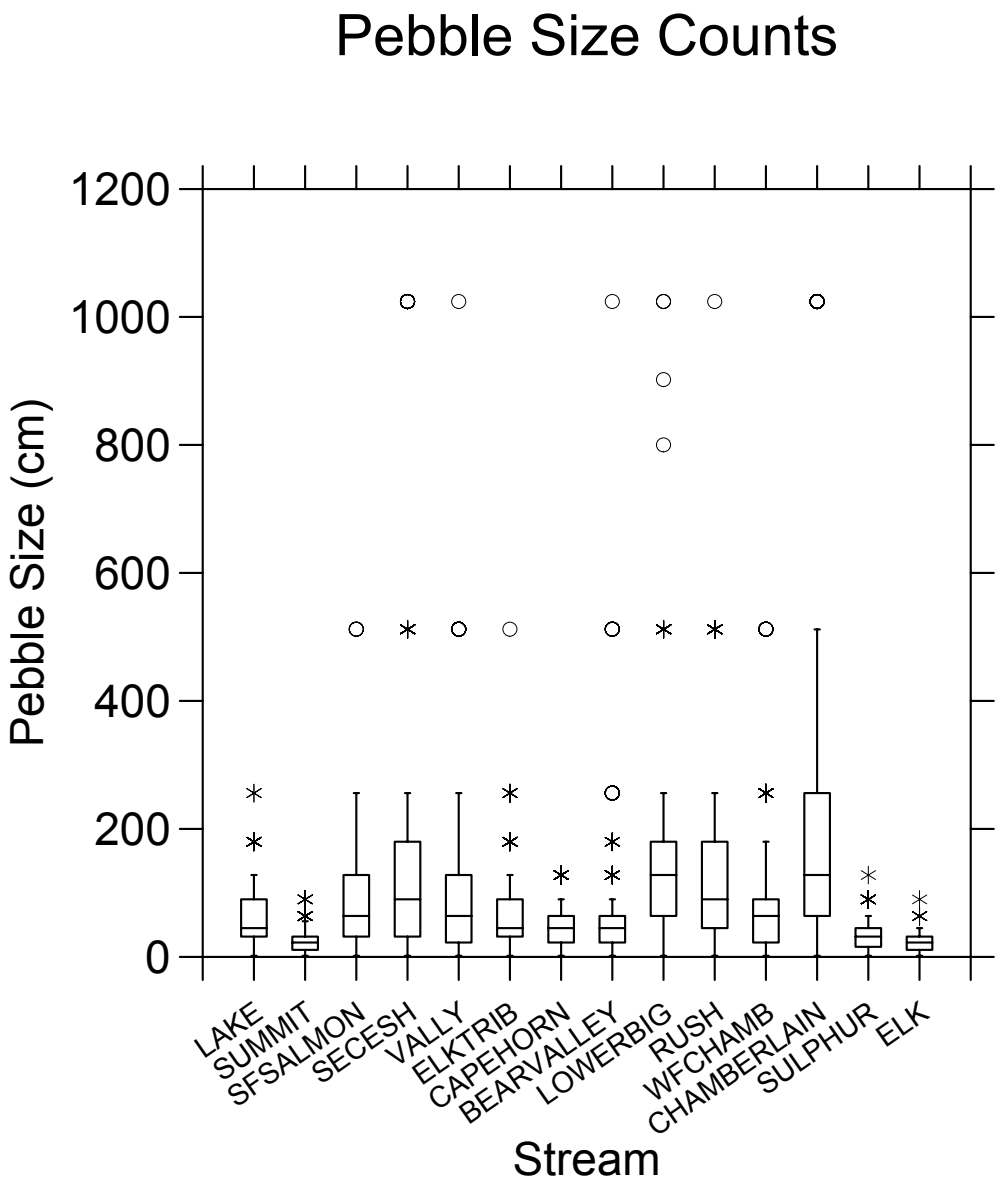

Figure 4. Box-Whisker plots showing the size distribution of pebbles measured in each stream sampling reach. The box indicates the inner 50% of the observations, the median represented by the middle line. Whiskers show the range of values falling within the inner fences. Fences are calculated as the value of each quartile ± (1.5*length of the box). (*) indicates observations falling outside, and far outside (o) the inner fence values. Streams are identified along the x-axis. Pebble size was measured in centimeters. Sample sizes ranged from approximately 440-610 rocks per stream.

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